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ROCKET MEASUREMENTS IN THE IONOSPHERE DURING THE ECLIPSE OF 20 JULY 1963

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ABSTRACT

The behaviour of the ionosphere up to 200 km was observed in a series of rocket flights at Fort Churchill, Manitoba, during the solar eclipse of 20 July 1963. Six Nike-Apache rockets were instrumented to measure electron density, electron temperature, Lyman-α radiation and a band of X-rays (44 - 60 A). The electron density in the E region (90 - 160 km) was reduced during the eclipse without any significant change in the shape of the profile. The rocket data show a time lag between the minimum area of the visible solar disc and the minimum electron density of much less than 3 minutes. Comparison with ionosonde data indicates a minimum value of 1×10^{-7} cm^3 sec^{-1} for the effective recombination coefficient of the E layer. The rocket observations also indicate that the ionizing radiation causing the E layer is reduced during the eclipse in proportion to the intensity of the measured band of X-rays. The variation of electron temperature in the E region due to the eclipse is found to be small. The electron density in the D region (50 - 90 km) shows a more complex variation. Between 79 and 89 km a time lag of about 3 minutes is indicated, but at lower heights, as at greater heights, the time lag is much smaller. Below 72 km the effect of the eclipse on electron density is much more pronounced that at greater heights for the observations taken with 8% and 15% of the disc visible, but not for the observation taken with 60% of the disc visible.

TABLE OF CONTENTS

SECTION 1

INTRODUCTION

The behaviour of the ionosphere up to 200 km was observed in a series of rocket flights during the solar eclipse of 20 July 1963. The path of totality passed within 300 km of the rocket launch site at Fort Churchill, Manitoba. Figure 1 shows the relation of the solar eclipse to the rocket trajectory at 2106 UT which was the time of minimum area of the disc as seen from the rocket launch site. The minimum visible area of the disc was 6 percent at the ground and 12 percent at the peak of the trajectory.

The variation of the visible area of the disc during the eclipse is shown in Figure 2, which also indicates the launch times of the six Nike-Apache rockets. The first two vehicles were complete failures, exploding about 3 seconds after launch, but the remaining four vehicles performed perfectly, attaining altitudes between 196 and 200 km, and giving data during the last half of the eclipse. These observations and their interpretation are the subject of this paper.

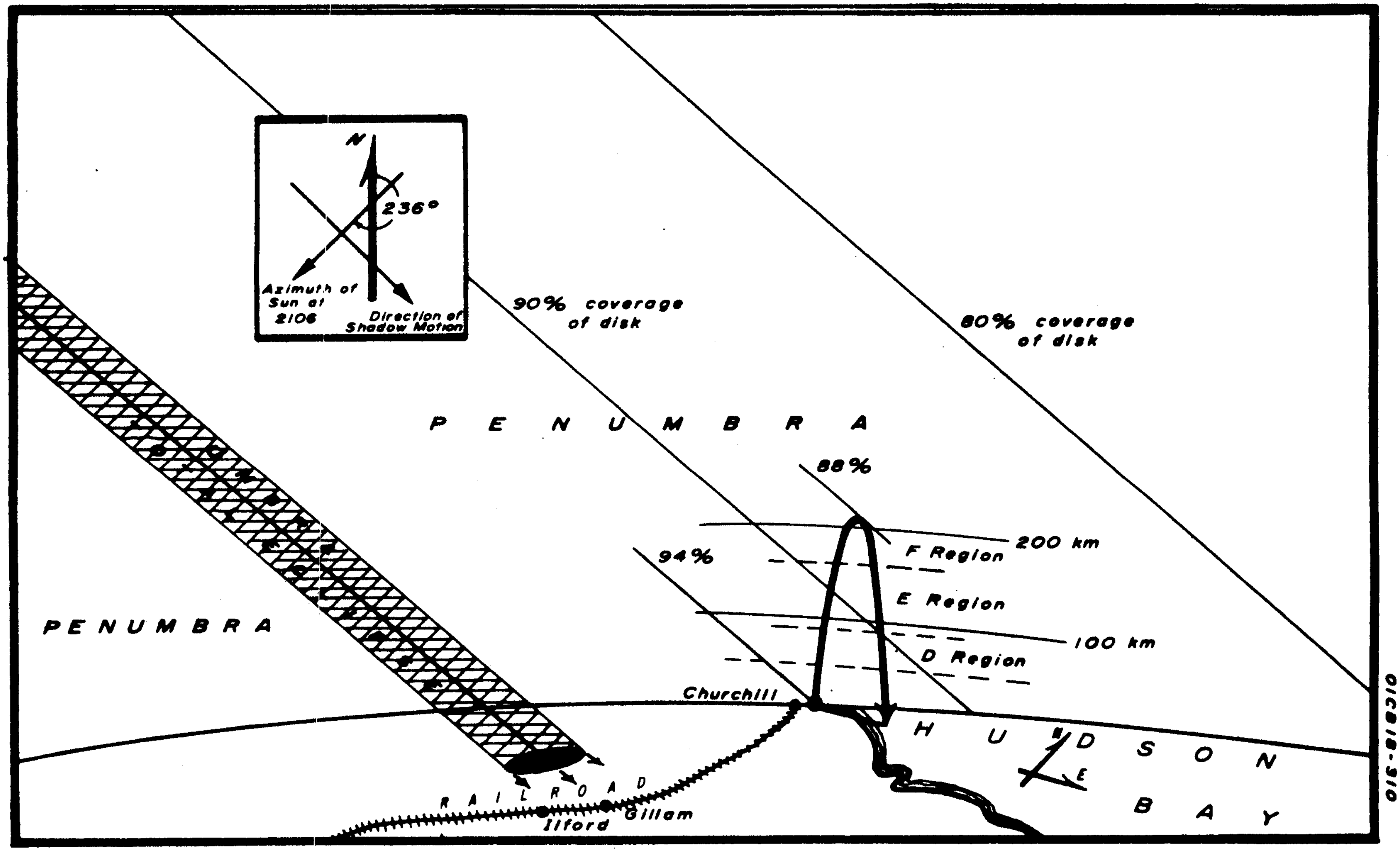

Figure 1. The solar eclipse of 20 July 1963 in relation to the rocket trajectory at Fort Churchill, Manitoba, at 2106UT.

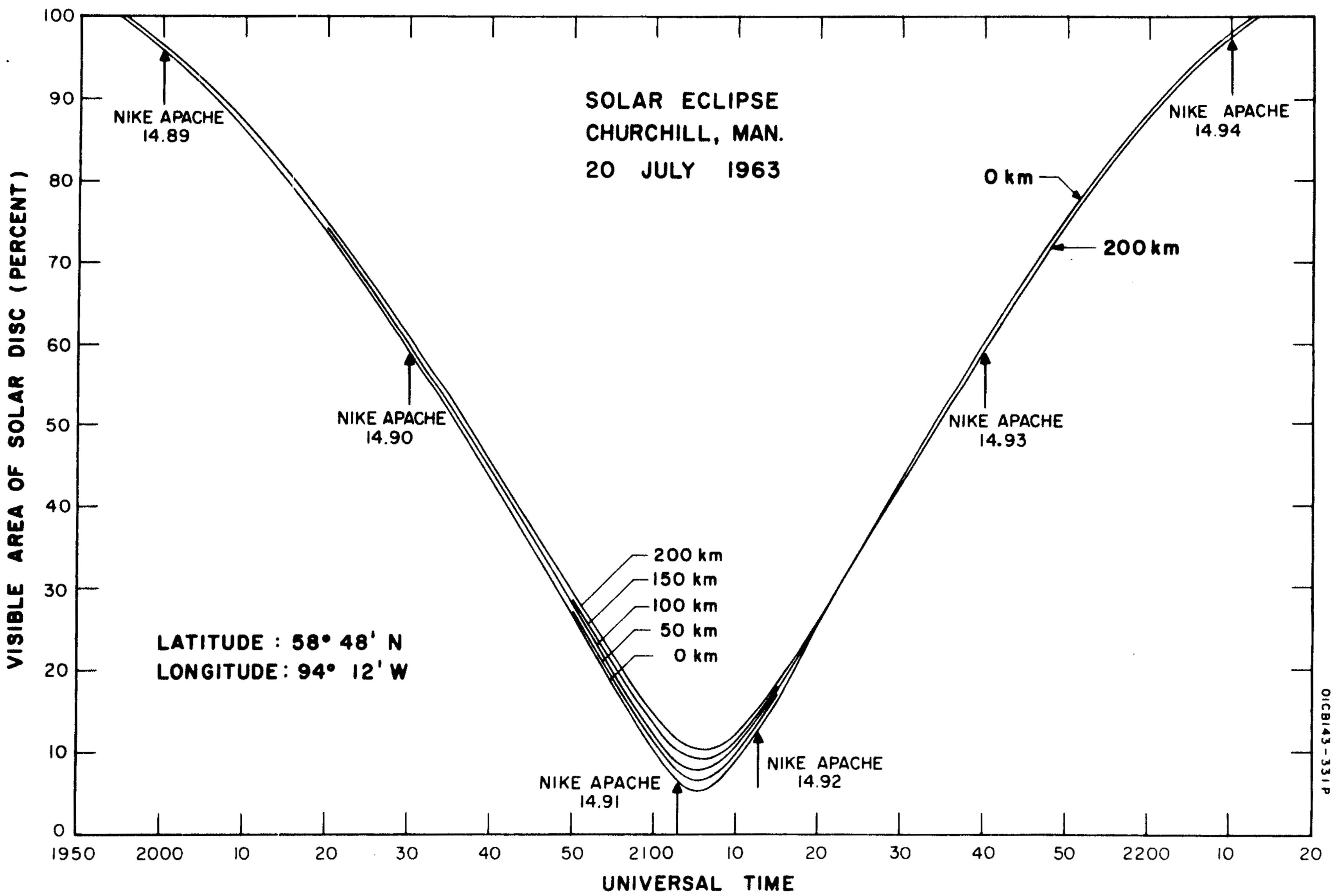

Figure 2. The variation of visible area of solar disc at altitudes up to 200 km above Churchill, Manitoba, 20 July 1963.

SECTION 2

INSTRUMENTATION

The payloads, identical with each other except for suitable adjustments in sensitivity, were instrumented to measure electron density and electron temperature and two bands of solar radiation. The nose tip of the rocket, seen in Figure 3, is insulated from the body of the rocket and its potential is swept from -2.7 volt to +2.7 volt. The variation of current with voltage is then analysed in the manner of the Langmuir probe technique to obtain electron temperature. The sweep which has a duration of 0.5 second is programmed onto the probe at intervals of 2 seconds. Between sweeps the electrode is held at a constant potential of +2.7 volt (with respect to the body of the rocket). The probe current is found to be proportional to electron density over wide ranges of height and electron density. Although its use in the D region below about 85 km is without theoretical basis, the technique does appear to give reasonable values of electron density as low as 55 km. The particular value of the fixed voltage method of measurement is that it permits observations of the fine structure of the electron density profile.

The Geiger counter used to measure the band of X-rays between 44 and 60 A can be seen in Figure 3 and below it an ion chamber having a

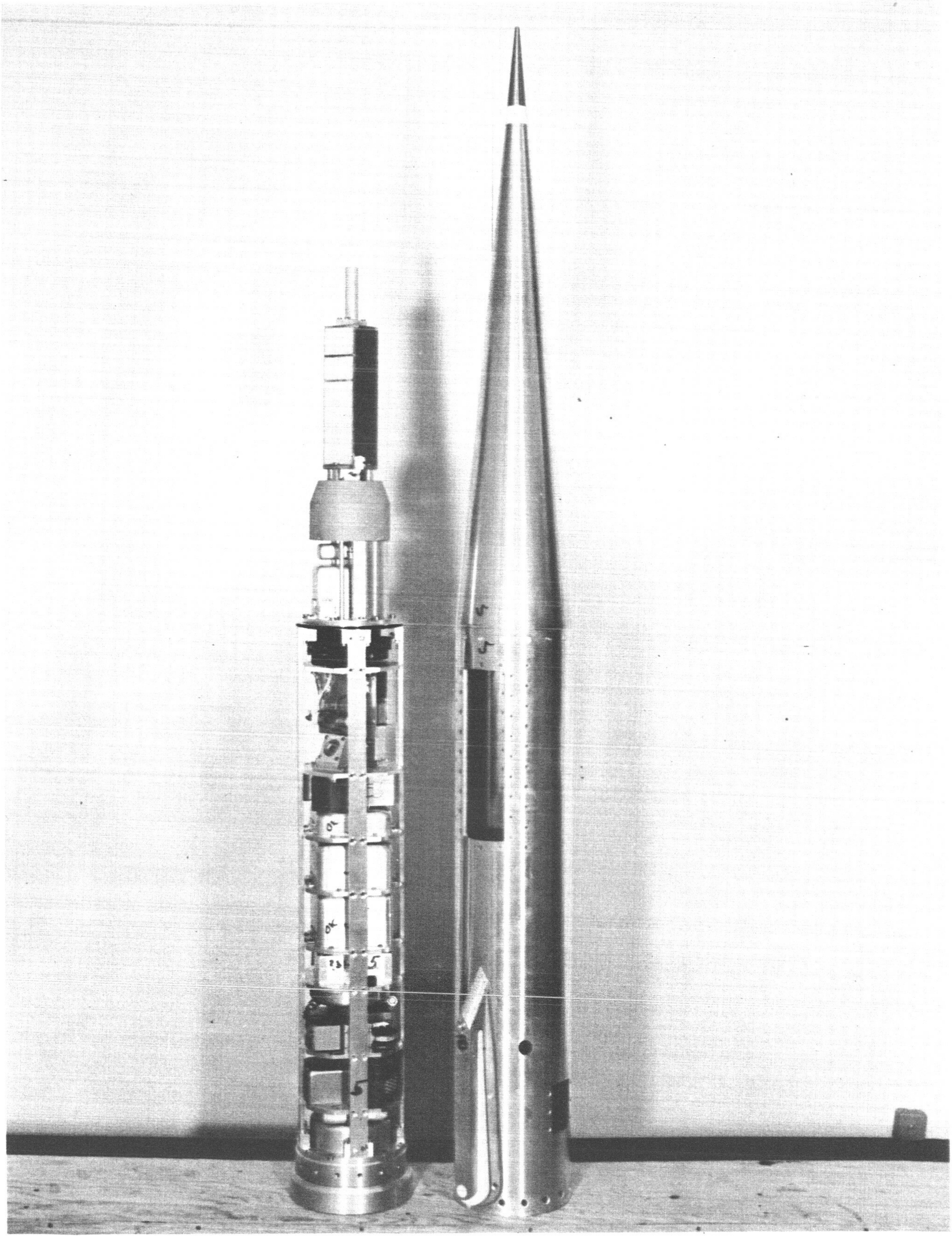

Figure 3. One of the six Nike-Apache payloads.

range from 1050 to 1240 A. In this range the major part of the radiation is Lyman-α (1216 A). Both these detectors are oriented at 60° to the forward direction; an additional Lyman-α ion chamber on the opposite side is oriented at 90° to the forward direction. These detectors and two solar aspect sensors are protected by doors in the launch phase.

The trajectory of the rocket was obtained without radar; the vertical component was derived by a time-of-flight method using a baroswitch to establish a reference altitude while the horizontal component was obtained from sound ranging of the impact. An accuracy of better than 1 km in height is obtained in this way.

The ionosonde station at Fort Churchill took observations at one minute intervals for a four hour period about the eclipse.

SECTION 3

OBSERVATIONS

The measurements of probe current show that the shape of the electron density profile is maintained without systematic change in the E region (90 - 160 km) and into the F_1 region up to a height of at least 195 km. Some deviations are observed but these are believed to be irregular variations of the electron density. Figure 4 shows the profiles below 120 km normalized to unity at 105 km. Below 90 km in the D region the four curves do not coincide and a more complicated variation is indicated.

The relaxation time or "sluggishness" of the E layer is a very important quantity since it is used to determine the effective recombination coefficient α. The rocket data shows that this time must be less than three minutes, and the ionosonde observations, Figure 5, with its better time resolution, shows that this relaxation time is probably less than one minute. It appears that the value of α cannot be less than 1×10^{-7} cm^3 sec^{-1} and may be several times greater than this, at a height of about 105 km.

The absorption profiles of Lyman-α such as the one illustrated in Figure 6 shows good agreement with the 1962 US Standard Atmosphere if

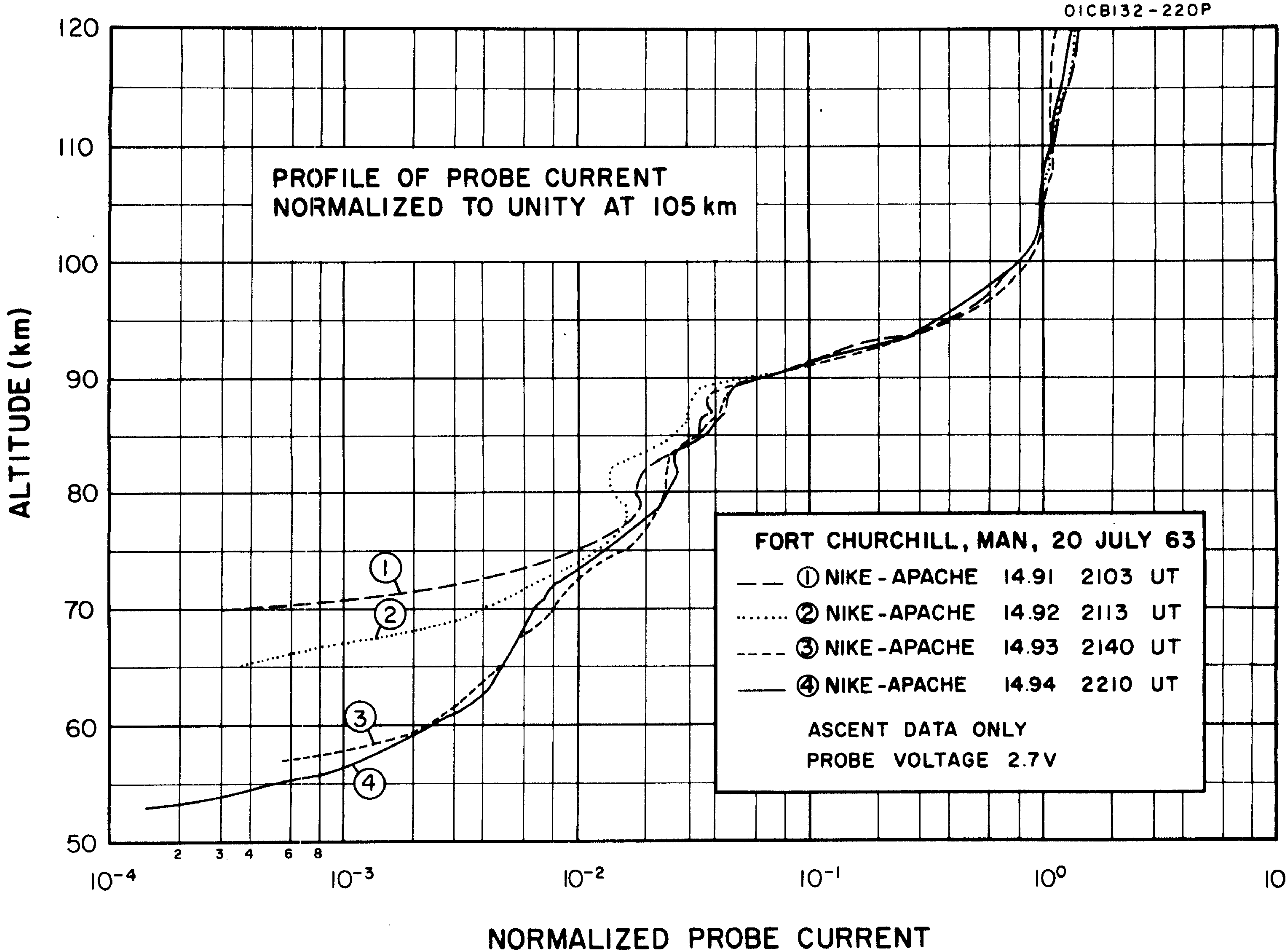

Figure 4. Profiles of probe current (proportional to electron density) normalized to unity at 105 km.

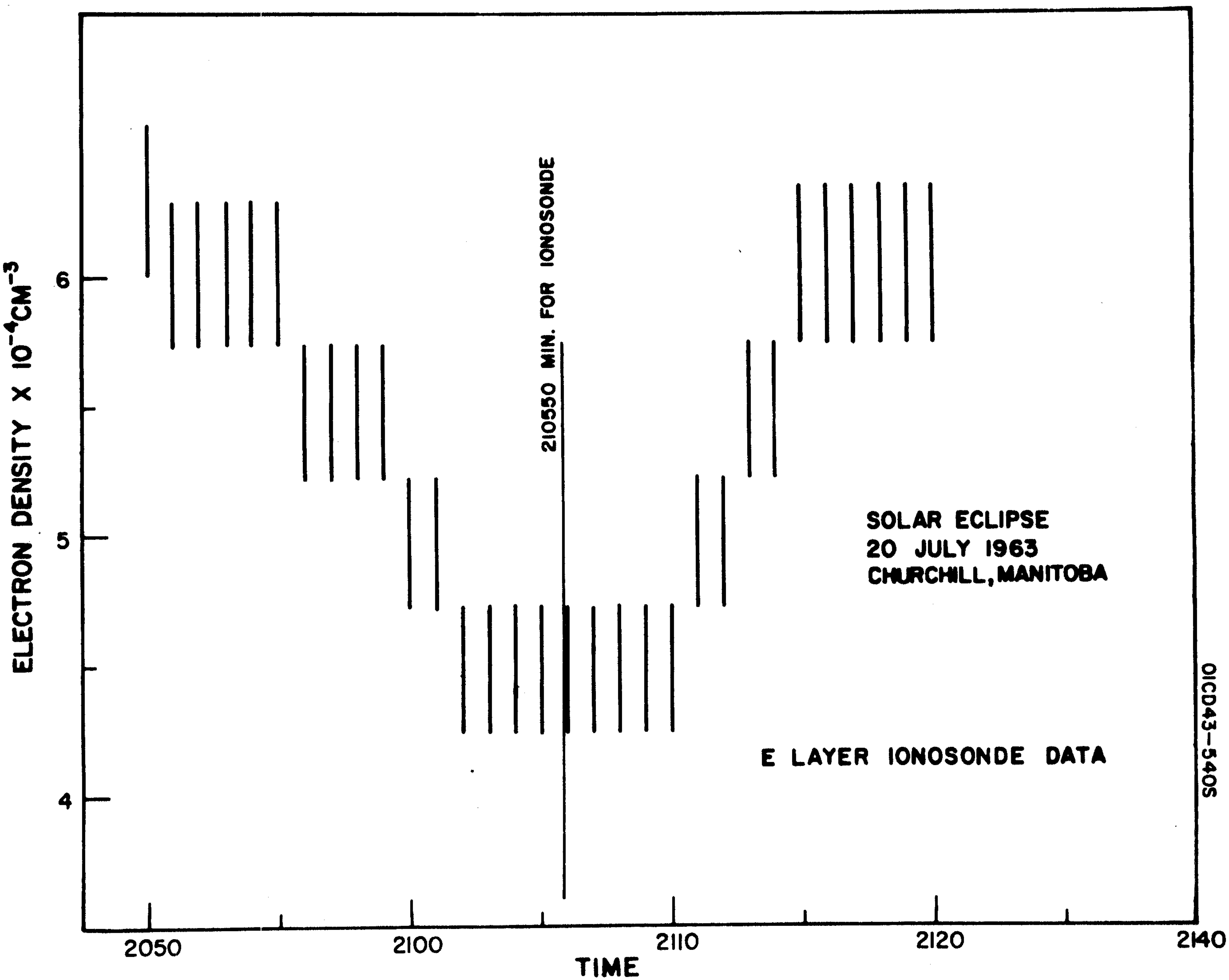

Figure 5. The variation in electron density in the E layer obtained by the ionosonde.

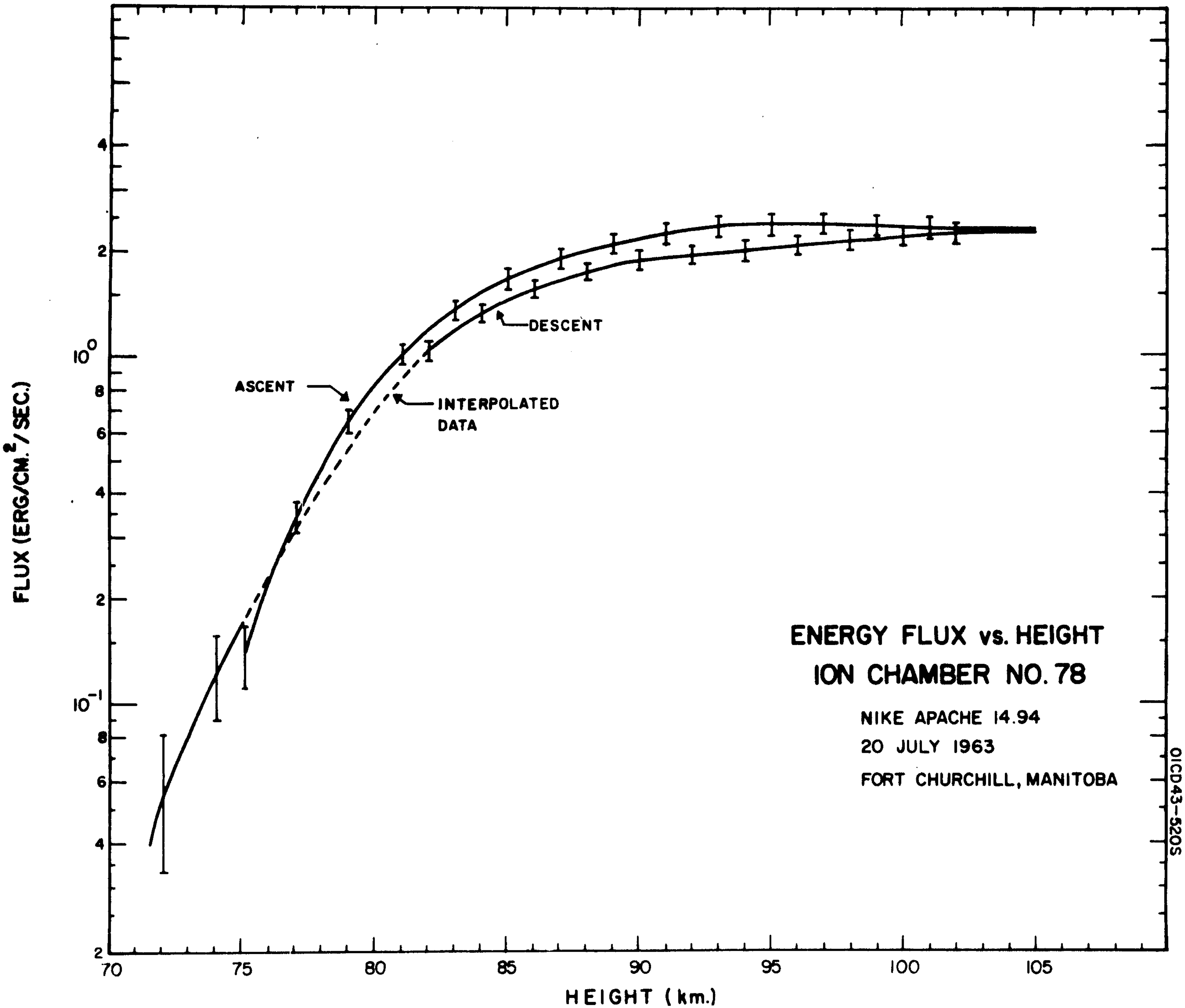

Figure 6. Absorption profiles of Lyman-α.

the theoretical curve is arbitrarily raised by 1 km. It is unlikely that the rocket altitude was in error by this much and probably indicates a difference between the real atmosphere and the model. The reduction in incident flux in the middle of the eclipse is summarized in Table 1. Since Lyman-α is radiated only from the visible disc these data indicate limb-brightening at this wavelength.

The absorption profile for the band of X-rays (44 - 60 A) is shown in Figure 7. The solid line is a theoretical profile which, as for Lyman-α, has been arbitrarily raised by one km. The large statistical errors are due to the difficulty of measuring small fluxes on a rapidly moving, rapidly spinning vehicle. The incident flux is measured much more accurately during the upper part of the trajectory.

The X-ray data is summarized in Table 2 and is compared with the ionosonde data. It will be noted that the X-ray flux is reduced much less than the area of the disc. The interpretation of this data depends on the relation between critical frequency and ionization rate. If the loss process for the E layer is taken to be recombination, as is usually the case in theoretical treatments, then $(f_oE)^4$ would be proportional to intensity. It would then be concluded that about half of the ionizing radiation is proportional to the area of the disc and half is proportional to the intensity of this band of X-rays. However, this law (i.e., $(f_oE)^4 \propto I$)

TABLE 1: Summary of Ion Chamber Data

Fort Churchill, Manitoba, 20 July 1963

Incident flux at last contact: 3.0 erg cm^{-2} sec^{-1}.

(Lyman-α flux estimated to be 80% of incident flux).

Nike-Apache	14.91	14.92
Time (at 90 km)	2104:12 UT	2114:11 UT
Ion Chamber (60°)	10.6%	13.7%
Ion Chamber (90°)	9.2%	18.6%
Area of Solar Disc	8.4%	15.4%

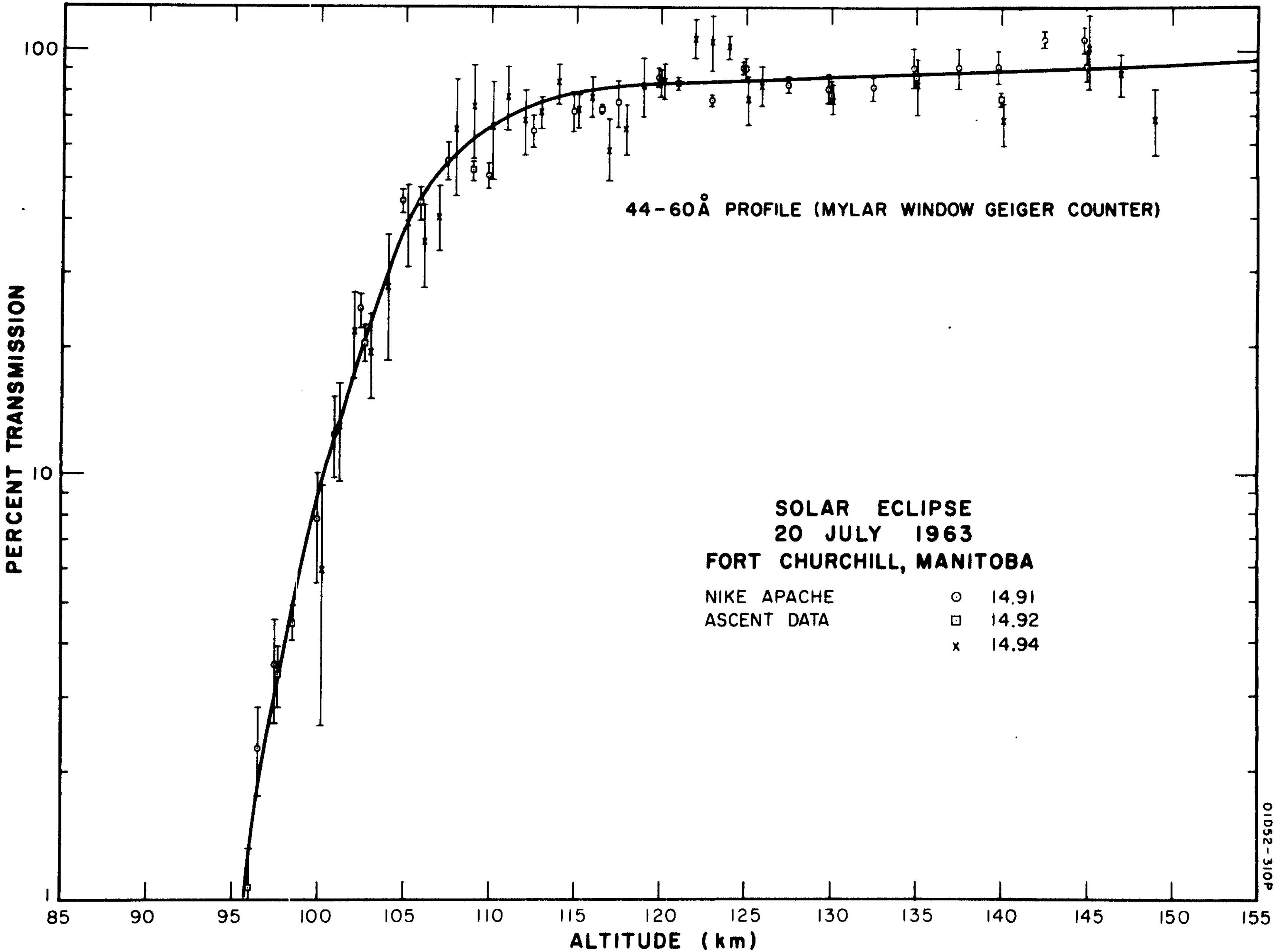

Figure 7. Absorption profiles of X-rays (44-60Å).

TABLE 2: Comparison of X-ray and Ionosonde Data

Fort Churchill, Manitoba, 20 July 1963

X-ray (44 - 60 A)		
Nike-Apache	14.91	14.92
Time (at 170 km)	2105:27 UT	2115:25 UT
Intensity	22 ± 2%	41 ± 4%
Area of Solar Disc	9.5%	17.0%
Ionosonde (E Layer)		
Time	2109:00 UT	2115:00 UT
Area of Solar Disc (at 105 km)	9.5%	17.0%
f_oE	1.90 mc/s	2.15 mc/s
$(f_oE/3.0)^3$	25 ± 2%	37 ± 3%
$(f_oE/3.0)^4$	16 ± 2%	26 ± 3%

is not supported by observations and, in fact, the variation of f_oE with zenith angle shows that $(f_oE)^3 \propto I$. Comparing the X-ray data with the ionosonde data using the $(f_oE)^3$ law, which represents the real behaviour of the E layer, shows that the ionizing radiation causing the E layer is reduced during the eclipse in proportion to the measured band of X-rays. It is therefore concluded that the major part of the ionizing radiation causing the E (and for that matter the F_1) layer originates outside the visible disc of the sun in agreement with the earlier work of Friedman and his group.

A measurement at totality does not help to decide between the two alternative interpretations since either of the two conclusions is consistent with a residual X-ray flux of about 20 percent of the uneclipsed radiation.

The final measurement relating to the E region is electron temperature, shown in Figure 8. The experimental error is rather large ($\pm$ 100°K) but above 160 km the temperature at the end of the eclipse is probably significantly greater than during the earlier part of the recovery phase.

The electron density profiles shown in Figure 9 have been prepared assuming that the probe current is proportional to electron density and

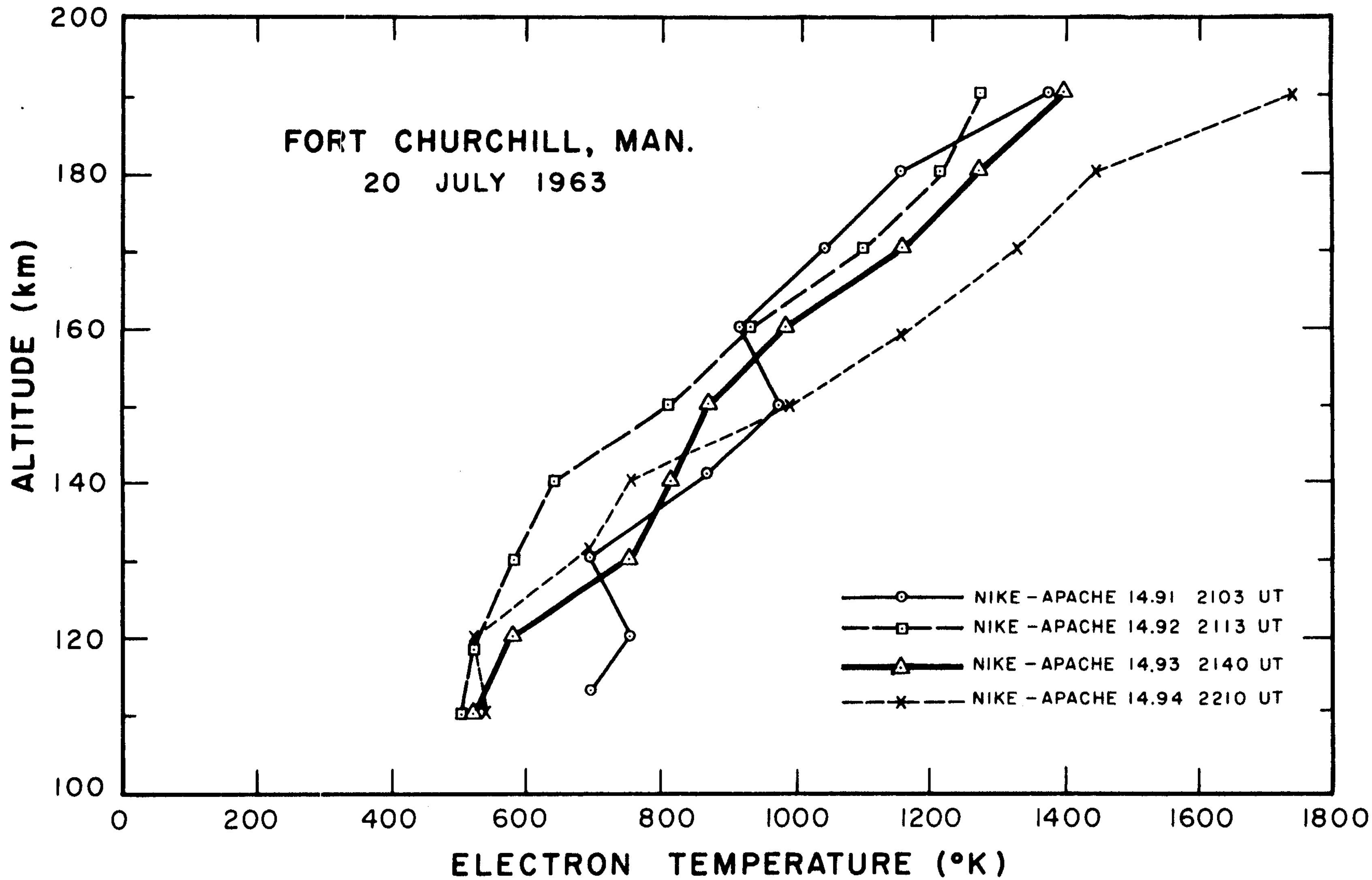

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Figure 8. Electron temperature measured during the eclipse.

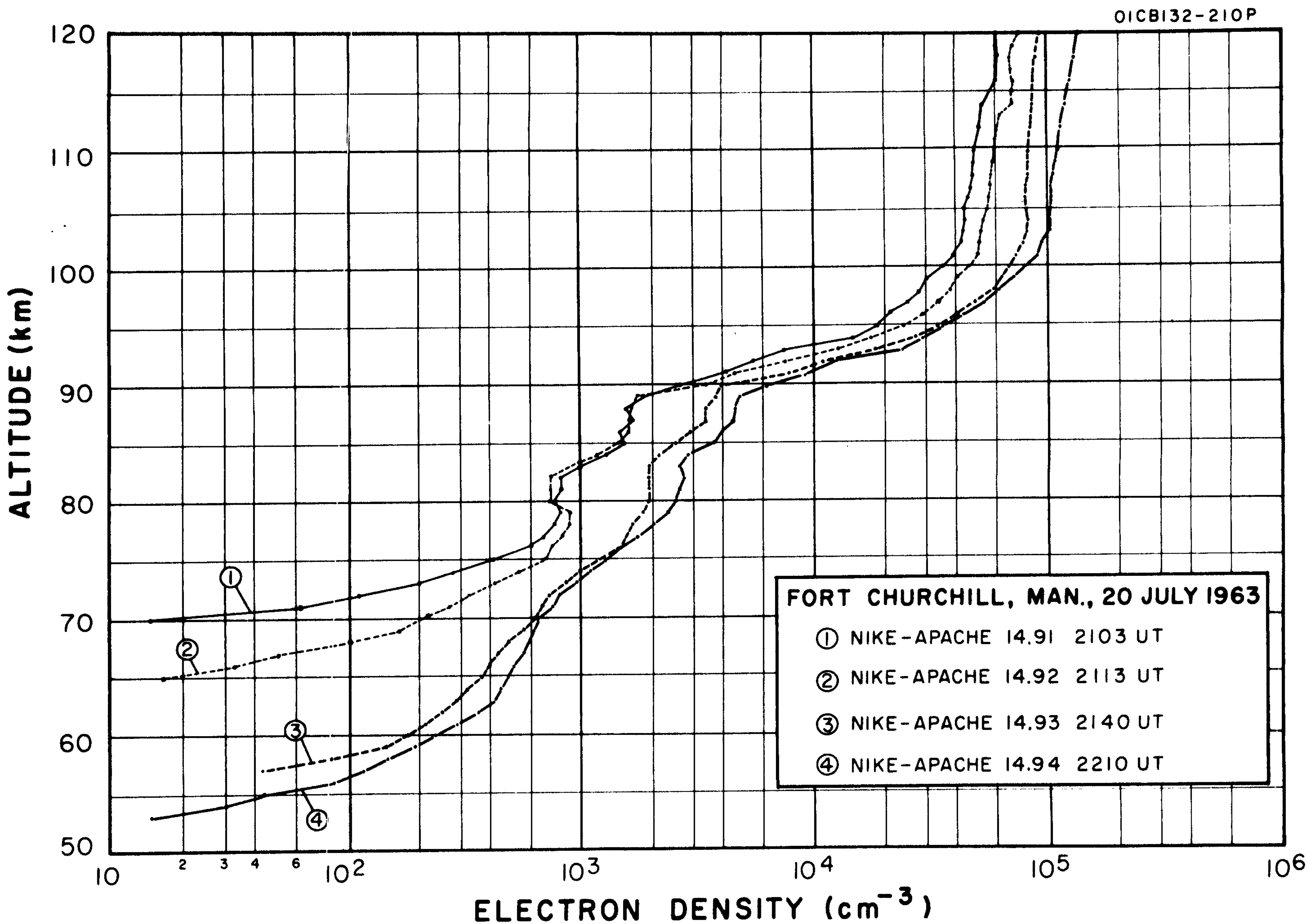

Figure 9. Electron density profiles in the D and lower E regions.

a scaling factor established with reference to the ionosonde E layer critical frequency. It must be remembered that the use of the probe in this way below 85 km is purely empirical, and the curves should be taken to show change in structure rather than absolute values of electron density.

The structural features of the normal D region can be identified in curve 4. The lower so-called C layer is observed from about 53 km up to 70 km. Above this up to about 82 km is the Lyman-α layer. From 82 to 89 km an unexplained region is found, characterised by small scale irregularities. Above 89 km the E layer may be identified. Two conclusions may be drawn from these profiles. First the relaxation time in the region from 79 to 89 km is about 3 minutes whereas at lower heights, as at greater heights, a much shorter relaxation time is indicated. The second conclusion is that below 72 km the effect of the eclipse on electron density is much more pronounced than at greater heights for the observations taken with 8% and 15% of the disc visible (curves 1 and 2) but not for the observation taken with 60 percent of the disc visible (curve 3). This appears to be consistent of the observations based on the propagation of very low frequency radio waves. It has been found that the effects on propagation at these frequencies are confined to the middle of the eclipse i.e. starting when about

50 percent of the disc is obscured and ending when about 50 percent of the disc is uncovered.

The interpretation of these observations in the lower part of the D region presents considerable difficulty. It is expected that the increase of electron density indicated between curves 1, 2 and 3 will be explained in terms of photodetachment, but simple theoretical considerations have not been adequate to account for such a large and rapid change.

We would like to express our appreciation for the contributions to this project made by C. M. Hendricks, Goddard Space Flight Center, and by J. O. Hillis, Churchill Rocket Range. The ionosonde data was scaled by B. Dundas and L. Medlicott, Canadian Department of Transport.